Certified Registered Nurse Anesthetists (CRNAs) perform epidural steroid injections for chronic back and extremity pain. Placing epidural needles using fluoroscopy and confirming the needle placement by epidurogram has been suggested as a means to increase the efficacy of epidural injections while decreasing complications. Because of the risk of radiation injury to patients and staff when using fluoroscopy, the purpose of this article is to review the concepts of fluoroscopy and radiation safety for CRNAs.

Following a literature search using keywords such as fluoroscopy, radiation injury, and radiation safety, relevant articles were identified. In addition, the reference lists of these articles were reviewed to identify other pertinent sources regarding this topic.

The risks of stochastic and deterministic effects from radiation exposure necessitate the need for practitioners who are knowledgeable in equipment, patient, and procedure related factors that influence radiation exposure. Practitioner conduct, using the as-low-as-reasonably achievable (ALARA) principle, results in choices regarding these factors that minimize the time and intensity of radiation exposure to patients, anesthesia providers, and staff.

Keywords: Epidural injections, fluoroscopy, radiation safety.

Current evidence supports the use of neuraxial injections, such as epidural steroid and intra-articular facet joint injections, for treating low back and radicular pain. For epidural steroid injections, the loss of resistance technique traditionally has been used for these injections; however, the accuracy and safety of epidural injections using this technique remains questionable. Recent studies indicate the accuracy of identifying the lumbar epidural space using loss of resistance to be 92% to 93% in nonobese patients. Some authors have estimated the rate of inaccurate needle placement to be more than 25%. Citing the rate of inaccurate needle placement, a recent clinical practice guideline for adult low back pain calls for the mandatory use of fluoroscopic confirmation of needle placement in epidural steroid injections. In addition, the transforaminal approach to the epidural space, using fluoroscopic guidance, may be useful in decreasing surgical interventions and providing better pain relief compared with the interlaminar approach in patients with radiographic evidence of nerve root compression. Intravascular injection is another concern when injecting medications into the epidural space. Stetanskii et al showed that 2% to 13% of epidural needle placements resulted in vascular uptake of contrast, but the aspiration of blood from the needle or the allotment for passive filling was not consistent.

Unfortunately, using fluoroscopy for these injections results in patient and personnel exposure to radiation, making the necessity of radiation safety apparent. In 1994, the US Food and Drug Administration issued a public advisory regarding the risk of radiation injury related to the use of fluoroscopy following an increase in reported radiation injuries in patients undergoing procedures under fluoroscopy. As the number of procedures using fluoroscopy increase, emphasis in radiation safety continues.

The purpose of this article is to review the basic concepts of fluoroscopic imaging, biologic effects of ionizing radiation, and radiation safety. While this article is intended to introduce various concepts to those contemplating the use of fluoroscopy, it is not intended to replace radiation safety courses for fluoroscopy users or specific equipment education.

The Fluoroscopic System

Figure 1 identifies the components of the fluoroscopic system. Functionally, the system consists of 3 components: an x-ray source, a detector, and display equipment. In addition, the fluoroscopic system has several components to limit radiation exposure to patients and improve image quality.

The x-ray source has 2 components: the x-ray generator and the x-ray tube. The x-ray generator is the portion of the system where the electrical current is altered before being transferred to the x-ray tube. The electrical current can be modified by adjusting either the amperage or the voltage. The amperage is variable either by quantity in milliampere (mA) or by duration expressed in milliampere seconds (mAs). Increasing the mA or the duration produces a greater quantity of radiation, which darkens the image. Voltage, measured in kilovolt peak (kVp), alters the energy level of the radiation but not the...
amount. Increasing the kVp produces x-rays of higher energy resulting in more penetration of the tissue. In the x-ray tube, electrical energy is transformed into x-rays by directing electrons from the x-ray generator toward a tungsten anode resulting in the production of an x-ray beam.

In fluoroscopic systems, the image intensifier detects the x-rays that have penetrated the tissue. Converting x-rays to optical photons, in a process called luminescence, occurs at the input phosphor of the image intensifier. However, the strength of the optical photons or light at this point is too low for adequate visualization and must be intensified. The optical photons are converted to photoelectrons that are accelerated, resulting in a significant increase in the number of optical photons at the output phosphor that produces an intensified image adequate for viewing. Image magnification is an additional function of the image intensifier. By decreasing the area used on the input phosphor or zooming in on the input phosphor, the resultant image is magnified; however, a higher intensity exposure is required to magnify the image resulting in a higher patient radiation dose.

Once the x-rays have been converted into a visible form, the image is transferred to a video monitor and recording device. The optical distributor transmits images from the image intensifier to the cameras in the fluoroscopic system. The optical distributor also provides the feedback to the automatic exposure control (AEC) of the x-ray generator. The AEC functions automatically to adjust the radiation intensity to maintain a constant brightness at the display monitor. The AEC is preprogrammed to alter the kVp, mA, and pulse width in a combination that results in low, medium, or high dose rates. At the low dose rate, the kVp is maximized before mA increases, thereby enhancing penetration while limiting patient radiation dose. At the high dose rate, image contrast is enhanced by increasing the amperage but at the cost of increased patient exposure. This is an important function to note since the level of radiation to the patient can be increased automatically. For example, using leaded surgical gloves will increase the patient exposure since the AEC will increase radiation output to penetrate the glove to maintain constant brightness at the display monitor.

Several other features of the fluoroscopic system that affect radiation dose or image quality are the collimator, filters, and grid. The collimator is a set of radio-opaque blades that alter the size of the x-ray beam. Using the collimator to decrease the size of the beam results in less tissue exposure. In addition, less radiation results in less scatter radiation that enhances the image quality.

Anti–scatter grids are another method of enhancing image quality by reducing the amount of scatter radiation that reaches the image intensifier. The grids consist of radio-opaque strips alternating with radiolucent spaces. The x-rays from the primary beam pass through the spaces while the strips reduce scatter radiation. Unfortunately, grids require higher radiation exposure. However, in fluoroscopic application where the image intensifier is positioned away from the patient, such as with interventional pain management techniques, little scatter radiation reaches the image intensifier subjugating the need for the anti–scatter grid. Removal of the grid can significantly reduce the radiation exposure to the patient.

Filters are another radiation-limiting device. With any x-ray imaging system, low-energy x-rays exist that will enter patient tissue but not have sufficient energy to exit the patient and strike the detector. By adding a filter, commonly made of aluminum, low-energy radiation is attenuated resulting in less radiation exposure to the patient.

Tissue Effects of Radiation

X-rays are a form of radiation that transfer sufficient energy to matter to dislodge electrons and thus is termed ionizing radiation. Ionizing radiation can damage tissue directly from cells absorbing energy or indirectly from free radical production in the area surrounding the cells. Direct injury results in damage to cell components most notably deoxyribonucleic acid. Indirect injury occurs from tissue interaction with free radicals produced from radiolysis of water in the tissue.
Biologic effects of ionizing radiation are either stochastic or deterministic. Stochastic effects are those such as malignancies and mutations that increase in frequency but not necessarily in severity, with increasing radiation doses. Deterministic effects, such as skin injury, are those that increase in frequency and severity with increasing radiation dose. While deterministic effects, by definition, are dose dependant, stochastic effects can occur at any exposure level and thus provide the rationale for limiting radiation exposure to the smallest amount possible in all cases.17

Several terms commonly used to describe the quantity of radiation are dose and exposure. Dose refers to the absorbed dose or the amount of energy deposited in the tissue. The System International unit for dose is the gray (Gy), formerly known as the radiation-absorbed dose (rad), where 1 Gy equals 100 rad. Exposure refers to the intensity of radiation at a point in space and is commonly referred to as air kerma, which is kinetic energy released per unit mass of air, also measured using the gray.16 Table 1 lists some threshold doses for injuries.

### Patient Safety

Limiting or preventing deterministic effects includes monitoring patient dose and employing techniques to decrease radiation exposure. While many simple techniques can substantially reduce radiation exposure, quantifying patient doses remains difficult. Receptor-entrance exposure rates reflect the total amount of radiation received by the receptor but do not take into account different skin exposures produced by different beam angles such as anterior-posterior vs lateral imaging. Likewise, skin-entrance exposure rates can be determined; however, this process is difficult because of such factors as patient size, distance from x-ray source, and variations in kVp and mAs. Real-time data to make patient care decisions is not available with this method. Direct dose estimation is possible using detectors placed at the skin entrance; however, these techniques are limited because (1) the patient will lie on the detector if the x-ray source is below the table, and (2) these devices will appear in the image field. The dose-area product (DAP) is the most common method of dosimetry providing an indirect estimate of dose. The DAP, expressed in rad or gray per square centimeter, is measured from a meter on the collimator. Since the DAP is the product of the exposure and the field size, it can be the same from a high dose over a small field or a low dose over a large field with the former representing a significantly higher skin-entrance dose.17 Although

### Table 1. Threshold Doses for Skin Injuries

<table>
<thead>
<tr>
<th>Effects</th>
<th>Threshold (Gy)</th>
<th>Onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early transient erythema</td>
<td>2</td>
<td>2-24 h</td>
</tr>
<tr>
<td>Main erythema</td>
<td>6</td>
<td>10 d</td>
</tr>
<tr>
<td>Temporary epilation</td>
<td>3</td>
<td>3 wk</td>
</tr>
<tr>
<td>Permanent epilation</td>
<td>7</td>
<td>3 wk</td>
</tr>
<tr>
<td>Dermal necrosis</td>
<td>12</td>
<td>52 wk</td>
</tr>
</tbody>
</table>

### Table 2. Techniques to Limit Radiation Exposure

<table>
<thead>
<tr>
<th>Technique</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>As low as reasonably achievable</td>
<td>This includes minimizing both the intensity and the time of exposure to the minimal amount necessary to complete the procedure.</td>
</tr>
<tr>
<td>(ALARA) principle</td>
<td></td>
</tr>
<tr>
<td>Last image hold function</td>
<td>This allows examination of image without exposure.</td>
</tr>
<tr>
<td>Pulsed mode function</td>
<td>For continuous fluoroscopy, the pulsed mode reduces the frame rate for acquired images for continuous fluoroscopy and increases the display rate of these images producing a continuous image but at substantially reduced exposure rates.</td>
</tr>
<tr>
<td>Collimator</td>
<td>Reducing the field size exposes only the area of interest, decreasing radiation exposure to surrounding tissue. Collimation also reduces scatter, which degrades image quality and results in provider exposure.</td>
</tr>
<tr>
<td>Intermittent fluoroscopy</td>
<td>By producing an image, adjusting the needle or fluoroscopy unit, then producing another image the radiation exposure is decreased when compared to using continuous fluoroscopy.</td>
</tr>
<tr>
<td>Low-dose setting</td>
<td>Decreasing the current at the x-ray tube, results in less radiation exposure to the patient.</td>
</tr>
<tr>
<td>Automatic exposure control (AEC)</td>
<td>The AEC reduces exposure by taking advantage of preprogrammed voltage-current configurations that optimize images while minimizing exposure.</td>
</tr>
<tr>
<td>Inverse square law</td>
<td>When positioning the x-ray tube, doubling the distance from the patient to the x-ray tube decreases the exposure by a factor of 4.</td>
</tr>
<tr>
<td>High dose modes (should be limited)</td>
<td>Greater exposure results from use of continuous, high-dose, and magnification modes.</td>
</tr>
<tr>
<td>Dose-area product (DAP)</td>
<td>Try to minimize the DAP reading for procedures.</td>
</tr>
</tbody>
</table>
DAP is not a good predictor of skin entrance dose,\(^{18}\) it can be used as a benchmark for performance improvement activities.\(^{19}\)

An estimate of exposure for patients is necessary, but an equally important aspect of radiation safety is knowledge of techniques to reduce the amount of radiation to the smallest amount to complete the procedure. Decreasing exposure in patients receiving interventional pain management procedures involves several practical techniques that have been summarized in Table 2.

**Practitioner Safety**

Personnel safety is another important aspect of radiation safety. The practitioners are exposed to radiation directly by having their hands in the beam or indirectly by scatter radiation from the patient. In a process known as the Compton effect, x-ray photons interact with the patient tissue and result in some of the photons losing energy to the tissue with subsequent redirection of the photons. The photons leave the patient but are not captured by the image intensifier and thus can be transferred to personnel in the immediate area. This process is responsible for the majority of practitioner exposure during fluoroscopy.\(^ {19}\) The highest concentration of scatter radiation is in the area adjacent to the x-ray tube (Figure 2).\(^ {20}\)

Shielding, personnel position, and limiting patient exposure are 3 important aspects of radiation safety for practitioners and staff. Shielding primarily involves the use of lead aprons with thyroid collars. Moveable devices, such as floor and table-mounted shields also are used for personal shielding. Movable shields placed near the x-ray source function to create areas of shadow. Immediately behind the shield, the area of protection is the same size as the shield, but the area of protection increases as the distance from the shield increases (Figure 3).\(^ {16}\)

Two concepts are important in the position of personnel. First, using the inverse-square law, doubling the distance from the x-ray source reduces the intensity of the...
radiation by a factor of 4. The practitioner and staff should try to maintain the maximum distance feasible from the x-ray source. Second, the practitioner should realize the area of high intensity scatter radiation is at the skin entrance point of the patient. Therefore, by standing near the image intensifier, the practitioner is positioned in the area of low intensity scatter.20

Practices that decrease patient exposure also decrease practitioner and staff exposure. The concept underscores the importance of limiting the intensity and duration of x-ray production. In addition to the aforementioned techniques to decrease patient exposure, proper equipment function must be ensured.20

Conclusion

The ability to visualize the structure under the skin is a powerful tool in providing injections for chronic pain. In addition to spinal injections, Certified Registered Nurse Anesthetists might perform other procedures using fluoroscopy such as placing central venous catheters and peripherally inserting central venous catheters. There are reports of using fluoroscopic guidance for regional anesthesia as well. Nishiyama et al21 proposed a brachial plexus block technique using fluoroscopy. Eidelman et al22 described a case of using fluoroscopy to place a spinal block in an obese patient. As the number of obese patients increase, fluoroscopy might be useful when external landmarks for regional injections are not palpable. However, with the use of such technology comes the responsibility to provide for patient and personnel safety. Understanding the equipment, physics, biology, and principles of radiation safety is the cornerstone of safe practice.

REFERENCES


AUTHOR

Gerry E. Fink, CRNA, MS, is a staff anesthetist at Frances Mahon Deaconess Hospital, Glasgow, Montana. Email: gerry.fink@fmdh.org.